Fisheries Research 175 (2016) 10–23

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Can a spatially-structured stock assessment address uncertainty due to closed areas? A case study based on pink ling in Australia

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ARTICLE INFO

Article history:
Received 4 August 2015
Received in revised form 3 November 2015
Accepted 8 November 2015

Keywords:
Age-structured stock assessment methods
Closed areas
Simulation
Spatial structure

ABSTRACT

Spatial structure in biological characteristics and exploitation rates impact the performance of stock assessment methods used to estimate the status of fish stocks relative to target and limit reference points. Spatially-structured stock assessment methods can reduce the bias and imprecision in the estimates of management-related model outputs. However, their performance has only recently been evaluated formally, in particular when some of the area fished is closed. In order to evaluate the effects of closed areas and spatial variation in growth and exploitation rate when estimating spawning biomass, a spatially-explicit operating model was developed to simulate spatial data, and five configurations of the stock assessment package Stock Synthesis (three of which were spatially structured) were applied. The bias in estimates of spawning stock biomass associated with spatially-aggregated assessment methods increases in the presence of closed areas while these biases can be reduced (or even eliminated) by applying appropriately constructed spatially-structured stock assessments. The performance of spatially-aggregated assessments when estimating spawning stock biomass is found to depend on the interactions among spatial variation in growth, in exploitation rate, and in knowledge of the spatial areas over which growth and exploitation rate are homogeneous.

1. Introduction

Punt et al. (2015a) developed a simulation framework to evaluate the performance of various stock assessment methods implemented using Stock Synthesis (Methot and Wetzell, 2013) in the face of spatial structuring of fished populations. The assessment configurations considered by Punt et al. (2015a) ranged from models that aggregated catch, length-frequency and conditional age-at-length data over space, to treating spatial regions as "fleets", and to spatially-explicit models. The testing framework was based on the Southern and Eastern Scalefish and Shark Fishery (SESSF) for pink ling, *Genypterus blacodes*, off southern Australia (Smith et al., 2008). The SESSF covers the region from southern Queensland, around Tasmania, to Cape Leeuwin in Western Australia. Allowance was made for three spatial zones (nominally zones 10, 20, and 30 of the SESSF; Fig. 1). The fish populations in these three zones were assumed to be connected through the distribution of age-0 animals, with animals of age-1 and older being sedentary. Two fleets (essentially trawl and non-trawl) were assumed to operate in each zone, growth could differ among zones, and recruitment was assumed to be stochastic, with spatial variation in the proportion of the total recruitment that settles to each zone, as well as temporal variation in total recruitment.

Numerous small marine closures exist in south-east Australia, both for biodiversity conservation (under an Australian federal government initiative to establish a National Representative System of Marine Protected Areas (NRSMPA); Anon. (2015)) and for fisheries management (declared under the Commonwealth Fisheries Management Act, 1991). Pink ling is assessed as two separate stocks, separated east and west at 147°E, but with a single total allowable catch for management purposes. Since 2005, four seasonal closures (from approximately September to November) have been in place to protect the spawning stock and reduce fishing mortality of pink ling at Maria Island, Seiner's Horseshoe and Everard Horseshoe in the east, and the Ling Hole in the west (Fig. 1). Closures within these areas have been both voluntary and legislated (SEMAC, 2012). These particular closures are relatively small in area, but are considered among the most productive and previously favoured fishing grounds.

The simulations conducted by Punt et al. (2015a) showed that non-spatial assessment configurations that aggregate data spatially provided more precise, but biased estimates of initial and final spawning biomass, as well as of the ratio between final and ini-

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http://dx.doi.org/10.1016/j.fishres.2015.11.008

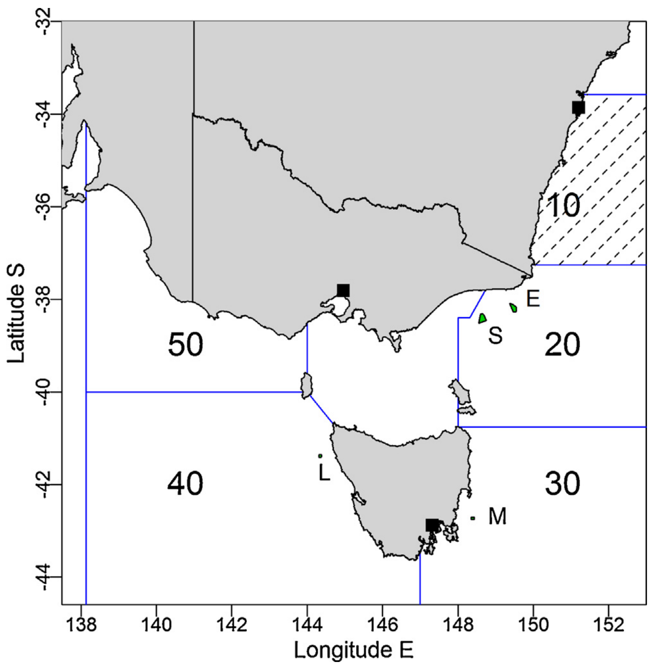

Fig. 1. Schematic map of SESSF reporting blocks 10–50, with the fine blue lines representing block boundaries. The locations of Sydney, Melbourne, and Hobart are indicated by black squares from top to bottom. The east stock of pink link is found in zones 10, 20 and 30; the line between zones 30 and 40 is at 147°E. The cross-hatched zone is the area closed to fishing in the bulk of the simulations; the real world closures include M, Maria Island; S, Seiners Horseshoe; E, Everard Horseshoe; and L, the Ling Hole.

tial spawning biomass. In contrast, assessments that allowed for spatial structure generally provided imprecise and highly biased estimates, although performance could be improved by changing the relative weighting applied to different data types. The exception to this general conclusion was when the population dynamics model underlying the assessment matched the model used to generate the pseudo data sets. Punt et al. (2015a) recommended conducting sensitivity analyses based on several model configurations to select the most appropriate structure for an assessment based on, for example, residual patterns.

The analyses conducted by Punt et al. (2015a) did not account for the possibilities of closed areas. Rather, they assumed that the modelled fisheries operated over entire zones that are homogenous with respect to age- and size-structure, as well as relative density. In addition, the analyses conducted by Punt et al. (2015a) ignored the possibility of the availability of survey data. This paper therefore extends the analyses of Punt et al. (2015a) to examine the consequences, in terms of the ability to estimate time-trajectories of spawning biomass, of closed areas that encompass a large proportion of stock biomass (>15%) as well as the benefits of the availability of surveys in the closed (and open) areas.

Several studies have considered the performance of stock assessment methods in the face of spatial heterogeneity in exploitation rates (e.g. Fu and Fanning, 2004; Hulson et al., 2011, 2013; Goethel et al., 2015; Guan et al., 2013; Harford et al., 2015). In addition, several previous studies have evaluated the impact of closed areas on the performance of stock assessment methods. Punt and Methot (2004) showed that stock assessment methods that assume that the stock is distributed homogeneously across space will lead to biased results when this assumption is violated to a substantial extent, with the magnitude and direction of bias depending on the extent to which the assumptions underlying the stock assessment are violated. Garrison et al. (2011) and McGilliard et al. (2015) found that applying spatially-structured stock assessment methods reduced or eliminated the bias when there are large area closures. This present study extends these earlier studies by considering the possibility that growth and trends in fishing mortality may also vary spatially.

2. Methods and materials

The evaluation of alternative scenarios using simulation is based on specifying a model of the population dynamics. This ('operating') model is assumed to represent the truth for the simulations and is used to generate pseudo data sets. The pseudo data sets are then analysed using each of five configurations of the stock assessment package Stock Synthesis, and results are summarized to determine the overall performance of each configuration.

2.1. The operating model

The simulation evaluation involves an operating model that models a single population with spatial variation in age structure and a single stock-recruitment relationship. It includes spatial variation in growth and in the proportion of the total recruitment that settles by zone and can implement spatial closures. The operating model covers a 43-year period (nominally 1970–2012). The three zones are assumed to receive different proportions of the total recruitment in an unfished state (0.28, 0.49, and 0.23 respectively for zones 10, 20 and 30, which reflect roughly the relative amount of habitat for pink ling off southeastern Australia), with the extent of variation in spatial distribution, σ_ϕ, set to 0.7. Given a Beverton-Holt stock-recruitment relationship, the recruitment (at age-0) to zone z at the start of year y, R_y^z, is given by:

$$R_y^z = \frac{e^{\phi^z+\eta_y^z}}{\sum\limits_z e^{\phi^z+\eta_y^z}} \frac{4hR_0\tilde{S}_y/\tilde{S}_0}{(1-h)+(5h-1)\tilde{S}_y/\tilde{S}_0} e^{\epsilon_y-\sigma_R^2/2};\ \epsilon_y \sim N\left(0;\sigma_R^2\right);$$

$$\eta_y^z \sim N\left(0;\sigma_\phi^2\right) \tag{1}$$

where h is the "steepness" of the stock-recruitment relationship (Francis, 1992), R_0 is the unfished equilibrium recruitment, $\tilde{S}_y$ is total (over zones) spawning biomass, $\tilde{S}_0$ is the unfished total spawning biomass, ϕ^z defines the expected proportion of the total recruitment that settles to zone z, σ_ϕ determines the variation about the expected proportion recruiting by zone across years, and σ_R is the standard deviation among recruitment deviations in log space. Spawning biomass is defined as:

$$\tilde{S}_y = \sum_z \sum_a O_a^z \ N_{y,a}^{\text{fem},z} \tag{2}$$

where $N_{y,a}^{s,z}$ is the number of animals of sex s and age a in zone z at the start of year y, O_a^z is the product of maturity-at-age and weight-at-age (see Methot and Wetzell (2013) for details of how O_a^z is calculated) based on current stock assessment parameters.

The value for h is set to 0.75 and that for σ_R to 0.7 (Whitten and Punt, 2014). Punt et al. (2015a) outline the selectivity patterns by gear (assumed to be the same among zones). Fig. 2 shows the spatial variation in relative fishing mortality in the absence of closed areas. The fishery is assumed to start in zone 10 and then move progressively southward over time—this reflects the fact that the fisheries off southeast Australia started in the mainland ports (and within zone 10). As in Punt et al. (2015a), the maximum level of fishing mortality is assumed to be the same spatially, while the fully-selected fishing mortality for the non-trawl fleet is assumed to be half that for the trawl fleet. For consistency with the actual assessment for pink ling (Whitten and Punt, 2014), selectivity for the non-trawl fleet is assumed to be a monotonic logistic function